

# **Investigation of Condensed Phase inside Supercritical Ethylene Jets Using Small-angle X-ray Scattering (SAXS) Technique**

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Injection of supercritical fluid is an important research area in the development of air-breathing propulsion systems. The use of endothermic hydrocarbon fuels as primary coolant around airframe and combustor components can create thermally cracked hydrocarbon mixtures at supercritical conditions. The subsequent injection of the supercritical fluid into the combustor, which is typically at sub-critical conditions, can considerably affect the combustion behavior of an engine, due to liquid generation through homogeneous nucleation processes. The global structures of supercritical jets injected into a quiescent environment have been explored, using shadowgraph images and Raman scattering. Further understanding on the liquid condensation process during the injection of supercritical fluid, however, was limited by the capability of conventional diagnostic techniques. Consequently, the fundamental mechanisms associated with the homogeneous nucleation process has not yet been resolved to give detailed information on droplet size, droplet number density, and liquid volume fraction inside the plumes of supercritical jets. The other challenges in exploring the condensed supercritical jet lie in the highly dynamic features of jet expansion processes and droplet evaporation phenomenon.

Recently, the small-angle x-ray scattering (SAXS) technique available at the 8-ID beamline at the Argonne National Laboratory was utilized to characterize droplet properties inside condensed ethylene jets. Effects of injection temperature and injector internal geometries on droplet size and liquid content were investigated during the first series of studies. It was found that the SAXS technique is capable of measuring droplet size and liquid contents inside a dense jet. The measured droplet size is on the order of 500–1500 Å. The average droplet size weighted by volume increases with both axial and radial distance within the condensed jet, due to droplet evaporation processes. For injectors of a given diameter, the injection temperature is the dominant factor in determining droplet size and liquid content inside a condensed ethylene jet. At an injection temperature close to the ethylene critical temperature, the injected plume contains bigger droplets and higher liquid content. The effects of injector internal configuration on droplet size and liquid contents could not be clearly verified from these measurements.

The structures of condensed supercritical ethylene jets inside a rectangular injector were later explored during the second series of studies. The rectangular injector is equipped with diamond windows at various axial locations for x-ray access. Evolution of the internal flow properties, along with the effects of injection temperature and injector internal geometries on nucleation/growth processes, was investigated. It was found that the adopted injector design creates inconsistent flows, probably due to unexpected hardware issues. Nonetheless, the ability of the SAXS technique to measure tiny incipient

droplets generated from the homogeneous nucleation process is demonstrated. The measured incipient droplet size is in the range of 30–100 Å. An effort to utilize axisymmetric injectors made out of beryllium for the study of internal flow structures is currently underway. It is hoped that this new injector design will provide high-fidelity data for droplet properties both inside and outside the injector. The obtained data sets also have been utilized for the development of numerical modeling.